

Intrinsic Charm in Proton and J/ψ Photoproduction at High Energies

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Abstract

Based on a perturbative theory of quantum chromodynamics and non-relativistic quark model, associated J/ψ plus open charm photoproduction on charm quarks in a proton via partonic subprocess $\gamma c \rightarrow J/\psi c$ is discussed. It is shown that the value and energy dependence of the cross section for such process remarkably depends on the choice of charm distribution function in a proton. In the region of small $z = E_J/E_\gamma < 0.2$ the contribution of the $\gamma c \rightarrow J/\psi c$ subprocess in the inelastic J/ψ photoproduction spectra is larger than the contribution of the photon-gluon fusion subprocess. At the energy range of HERA collider intrinsic charm contribution in the total inclusive J/ψ photoproduction cross section may be equal to 4% of the dominant contribution of photon-gluon fusion mechanism.

1 Introduction

The study of the charm quark distribution function in a proton takes a remarkable interest from the point of view of a investigation of the non-perturbative proton wave function [1] as well as from the point of view of a calculation of the intrinsic charm quark contribution to the processes of charm particle and quarkonium production in photon-hadron, hadron-hadron and hadron-nucleus interactions at high energies [2, 3]. The existing data on charm production processes gives us the idea [1, 4] of a small, but finite (0.3%–0.5%), non-perturbative $c\bar{c}$ -component in proton wave function. It helps to explain some effects in charm production processes which are difficult for understanding in the assumption that charm quarks were produced only in hard partonic subprocesses [1].

The J/ψ photoproduction process is the best source of information about gluon structure function in a proton [5], especially in the region of very small x [6]. In the deep inelastic domain J/ψ photoproduction process may be described using so-called colour

singlet model [7, 8], in which J/ψ is produced in $\gamma g \rightarrow J/\psi g$ partonic subprocess. Obviously, in the proton fragmentation region the contribution of the intrinsic charm in proton via $\gamma c \rightarrow J/\psi c$ subprocess is too comparably large [9]. The partonic subprocess $\gamma c \rightarrow J/\psi c$ gives the main contribution to associated J/ψ plus open charm photoproduction and may be very clean test for charm quark sea in a proton.

In Sec.2 we shall obtain amplitude, differential and total cross section for partonic subprocess $\gamma c \rightarrow J/\psi c$ using perturbative theory of QCD and non-relativistic quark model. The connection of the partonic and measurable cross sections for processes $\gamma p \rightarrow J/\psi c X$ and $\gamma p \rightarrow J/\psi X$ is discussed in Sec.3. In that part we also present charm quark distribution functions which are used in calculations. In Sec.4 we shall calculate z -spectra and total cross sections for associated J/ψ plus open charm photoproduction process as well as the $\gamma c \rightarrow J/\psi c$ subprocess contribution to the inclusive J/ψ photoproduction cross section at high energies.

2 Partonic subprocess $\gamma c \rightarrow J/\psi c$

In the lowest order of QCD perturbative theory associated J/ψ plus open charm photoproduction in γp -interactions corresponds to partonic subprocess $\gamma c \rightarrow J/\psi c$. It is described by Feynman diagrams which are shown in Fig.1. The quarkonium is represented as non-relativistic quark-antiquark bound system in singlet colour state with specified mass $M = 2m$ (m is c -quark mass) and spin-parity $J^P = 1^-$.

The amplitude of subprocess $\gamma c \rightarrow J/\psi c$ can be expressed in the form:

$$M = M_1 + M_2 + M_3 + M_4, \quad (1)$$

where

$$M_1 = e_q e g^2 \bar{U}(q') \hat{\varepsilon}_\gamma \frac{\hat{q}' - \hat{k} + m}{(k - q')^2 - m^2} T^a \gamma_\mu \frac{\delta^{ab} g_{\mu\nu}}{(p - q)^2} T^b \hat{P} \gamma_\nu U(q), \quad (2)$$

$$M_2 = e_q e g^2 \bar{U}(q') \gamma_\mu T^b \hat{P} \frac{\delta^{ab} g_{\mu\nu}}{(p + q')^2} \gamma_\nu T^a \frac{\hat{k} + \hat{q} + m}{(k + q)^2 - m^2} \hat{\varepsilon}_\gamma U(q), \quad (3)$$

$$M_3 = e_q e g^2 \bar{U}(q') \gamma_\mu T^a \hat{P} \frac{\delta^{ab} g_{\mu\nu}}{(p + q')^2} \hat{\varepsilon}_\gamma \frac{\hat{p} - \hat{k} + m}{(p - k)^2 - m^2} \gamma_\nu T^b U(q), \quad (4)$$

$$M_4 = e_q e g^2 \bar{U}(q') \gamma_\mu T^a \frac{\hat{k} - \hat{p} + m}{(p - k)^2 - m^2} \hat{\varepsilon}_\gamma \hat{P} \frac{\delta^{ab} g_{\mu\nu}}{(p - q)^2} \gamma_\nu U(q). \quad (5)$$

In these formula:

$$\hat{P} = \frac{F_c}{\sqrt{2}} A \hat{\varepsilon}_J (\hat{p} + m),$$

$A = \Psi(0)/\sqrt{m}$, $F_c = \delta^{kr}/\sqrt{3}$, k and r are colour indexes of charm quarks, $T^a = \lambda^a/2$, e_q is electrical charge of q -quark in units of e . It is well known that $\Psi(0)$, which is equal to J/ψ wave function at zero point, can be extracted in the lowest order of perturbative QCD from the leptonic decay width of the J/ψ :

$$\Gamma_{ee} = 4\pi e_q^2 \alpha^2 \frac{|\Psi(0)|^2}{m^2}. \quad (6)$$

We shall put in our calculation $\Gamma_{ee} = 5.4$ KeV [10].

If we average and sum over spins and colours of initial and final particles, we obtain the expression for square of matrix element:

$$|\bar{M}|^2 = \frac{B_{\gamma c}}{m^2} \sum_{j \geq i=1}^4 K_{ij}(\tilde{s}, \tilde{t}, \tilde{u}), \quad (7)$$

where

$$B_{\gamma c} = \frac{32\pi^2 \alpha_s^2 \Gamma_{ee} m}{9\alpha},$$

$$\tilde{s} = \hat{s}/m^2, \quad \tilde{t} = \hat{t}/m^2, \quad \tilde{u} = \hat{u}/m^2,$$

$\hat{s}, \hat{t}, \hat{u}$ are usual Mandelstam variables and $\hat{s} + \hat{t} + \hat{u} = 6m^2$. The explicit analytical formula for functions K_{ij} have the following forms:

$$K_{11} = \frac{-(2\tilde{s}\tilde{t} - 2\tilde{s} + \tilde{t}^2\tilde{u} - 4\tilde{t}^2 - 8\tilde{t}\tilde{u} + 14\tilde{t} + 7\tilde{u} - 106)}{(4 * (\tilde{t}^4 - 4\tilde{t}^3 + 6\tilde{t}^2 - 4\tilde{t} + 1))} \quad (8)$$

$$K_{12} = \frac{(\tilde{s}^3 - \tilde{s}^2\tilde{t} - 6\tilde{s}^2 - \tilde{s}\tilde{t}^2 - 2\tilde{s}\tilde{t}\tilde{u} + 16\tilde{s}\tilde{t} - \tilde{s}\tilde{u}^2 + 8\tilde{s}\tilde{u} - 28\tilde{s} + \tilde{t}^3 - 6\tilde{t}^2 - \tilde{t}\tilde{u}^2 + 8\tilde{t}\tilde{u} - 28\tilde{t} + 4\tilde{u}^2 - 126\tilde{u} + 276)}{(4(\tilde{s}^2\tilde{t}^2 - 2\tilde{s}^2\tilde{t} + \tilde{s}^2 - 2\tilde{s}\tilde{t}^2 + 4\tilde{s}\tilde{t} - 2\tilde{s} + \tilde{t}^2 - 2\tilde{t} + 1))} \quad (9)$$

$$K_{13} = \frac{(\tilde{s}^2\tilde{t} + \tilde{s}^2 + 2\tilde{s}\tilde{t}^2 + \tilde{s}\tilde{t}\tilde{u} - 22\tilde{s}\tilde{t} + 7\tilde{s}\tilde{u} + 16\tilde{s} + 2\tilde{t}^2\tilde{u} - 24\tilde{t}^2 - 11\tilde{t}\tilde{u} + 217\tilde{t} - 2\tilde{u}^2 + 41\tilde{u} - 511)}{(2 * (\tilde{s}\tilde{t}^2\tilde{u} - 4\tilde{s}\tilde{t}^2 - 2\tilde{s}\tilde{t}\tilde{u} + 8\tilde{s}\tilde{t} + \tilde{s}\tilde{u} - 4\tilde{s} - \tilde{t}^2\tilde{u} + 4\tilde{t}^2 + 2\tilde{t}\tilde{u} - 8\tilde{t} - \tilde{u} + 4))} \quad (10)$$

$$\begin{aligned}
K_{14} = & -(\tilde{s}^3 + \tilde{s}^2\tilde{t} - 18\tilde{s}^2 + \tilde{s}\tilde{t}^2 + \tilde{s}\tilde{t}\tilde{u} - 16\tilde{s}\tilde{t} - \tilde{s}\tilde{u}^2 - 3\tilde{s}\tilde{u} + \\
& 166\tilde{s} - 11\tilde{t}^2 - 5\tilde{t}\tilde{u} + 115\tilde{t} + 13\tilde{u}^2 - 65\tilde{u} - 335)/ \\
& (2 * (\tilde{t}^3\tilde{u} - 4\tilde{t}^3 - 3\tilde{t}^2\tilde{u} + 12\tilde{t}^2 + 3\tilde{t}\tilde{u} - 12\tilde{t} - \tilde{u} + 4))
\end{aligned} \tag{11}$$

$$\begin{aligned}
K_{22} = & -(\tilde{s}^2\tilde{u} - 4\tilde{s}^2 + 2\tilde{s}\tilde{t} - 8\tilde{s}\tilde{u} + 14\tilde{s} - 2\tilde{t} + 7\tilde{u} - 106)/ \\
& (4 * (\tilde{s}^4 - 4\tilde{s}^3 + 6\tilde{s}^2 - 4\tilde{s} + 1))
\end{aligned} \tag{12}$$

$$\begin{aligned}
K_{23} = & -(\tilde{s}^2\tilde{t} - 11\tilde{s}^2 + \tilde{s}\tilde{t}^2 + \tilde{s}\tilde{t}\tilde{u} - 16\tilde{s}\tilde{t} - 5\tilde{s}\tilde{u} + 115\tilde{s} + \\
& \tilde{t}^3 - 18\tilde{t}^2 - \tilde{t}\tilde{u}^2 - 3\tilde{t}\tilde{u} + 166\tilde{t} + 13\tilde{u}^2 - 65\tilde{u} - 335)/ \\
& (4(\tilde{s}^3\tilde{u} - 4\tilde{s}^3 - 3\tilde{s}^2\tilde{u} + 12\tilde{s}^2 + 3\tilde{s}\tilde{u} - 12\tilde{s} - \tilde{u} + 4))
\end{aligned} \tag{13}$$

$$\begin{aligned}
K_{24} = & (2\tilde{s}^2\tilde{t} + 2\tilde{s}^2\tilde{u} - 24\tilde{s}^2 + \tilde{s}\tilde{t}^2 + \tilde{s}\tilde{t}\tilde{u} - 22\tilde{s}\tilde{t} - 11\tilde{s}\tilde{u} + \\
& 217\tilde{s} + \tilde{t}^2 + 7\tilde{t}\tilde{u} + 16\tilde{t} - 2\tilde{u}^2 + 41\tilde{u} - 511)/(2 * (\tilde{s}^2\tilde{t}\tilde{u} - 4\tilde{s}^2\tilde{t} \\
& - \tilde{s}^2\tilde{u} + 4\tilde{s}^2 - 2\tilde{s}\tilde{t}\tilde{u} + 8\tilde{s}\tilde{t} + 2\tilde{s}\tilde{u} - 8\tilde{s} + \tilde{t}\tilde{u} - 4\tilde{t} - \tilde{u} + 4))
\end{aligned} \tag{14}$$

$$\begin{aligned}
K_{33} = & -(2\tilde{s}^2 + 2\tilde{s}\tilde{t} + 6\tilde{s}\tilde{u} - 46\tilde{s} + \tilde{t}^2\tilde{u} - 10\tilde{t}^2 - \\
& 4\tilde{t}\tilde{u} + 74\tilde{t} + 2\tilde{u}^3 - 22\tilde{u}^2 + 53\tilde{u} - 118)/(\tilde{s}^2\tilde{u}^2 - 8\tilde{s}^2\tilde{u} + \\
& 16\tilde{s}^2 - 2\tilde{s}\tilde{u}^2 + 16\tilde{s}\tilde{u} - 32\tilde{s} + \tilde{u}^2 - 8\tilde{u} + 16)
\end{aligned} \tag{15}$$

$$\begin{aligned}
K_{34} = & -(2 * (\tilde{s}^2 + \tilde{s}\tilde{t} - 11\tilde{s} + \tilde{t}^2 + 2\tilde{t}\tilde{u} - 19\tilde{t} + \tilde{u}^3 - 9\tilde{u}^2 + 28\tilde{u} + 11))/ \\
& (\tilde{s}\tilde{t}\tilde{u}^2 - 8\tilde{s}\tilde{t}\tilde{u} + 16\tilde{s}\tilde{t} - \tilde{s}\tilde{u}^2 + 8\tilde{s}\tilde{u} - 16\tilde{s} \\
& - \tilde{t}\tilde{u}^2 + 8\tilde{t}\tilde{u} - 16\tilde{t} + \tilde{u}^2 - 8\tilde{u} + 16)
\end{aligned} \tag{16}$$

$$\begin{aligned}
K_{44} = & -(\tilde{s}^2\tilde{u} - 10\tilde{s}^2 + 2\tilde{s}\tilde{t} - 4\tilde{s}\tilde{u} + 74\tilde{s} + 2\tilde{t}^2 + 6\tilde{t}\tilde{u} - \\
& 46\tilde{t} + 2\tilde{u}^3 - 22\tilde{u}^2 + 53\tilde{u} - 118)/(\tilde{t}^2\tilde{u}^2 - 8\tilde{t}^2\tilde{u} + 16\tilde{t}^2 - 2\tilde{t}\tilde{u} \\
& ^2 + 16\tilde{t}\tilde{u} - 32\tilde{t} + \tilde{u}^2 - 8\tilde{u} + 16)
\end{aligned} \tag{17}$$

The differential cross section for subprocess $\gamma c \rightarrow J/\psi c$ can be written as follows:

$$\frac{d\hat{\sigma}}{d\hat{t}} = \frac{1}{16\pi(\hat{s} - m^2)^2} |\bar{M}|^2 \tag{18}$$

The total cross section will be obtained after integration over \hat{t} in limits:

$$\hat{t}_{min}^{max} = m^2 - \frac{\hat{s} - m^2}{2\hat{s}} [\hat{s} - 3m^2 \pm \sqrt{(\hat{s} - 9m^2)(\hat{s} - m^2)}].$$

This procedure can be made analytically, we find that:

$$\hat{\sigma}(\gamma c \rightarrow J/\psi c) = \frac{B_{\gamma c}}{16\pi(\hat{s} - m^2)^2} \sum_{j \geq i=1}^4 [H_{ij}(\tilde{s}, \tilde{t}_{max}) - H_{ij}(\tilde{s}, \tilde{t}_{min})], \quad (19)$$

where $\tilde{t}_{max} = \hat{t}_{max}/m^2$ and $\tilde{t}_{min} = \hat{t}_{min}/m^2$. The explicit expressions for functions $H_{ij}(\tilde{s}, \tilde{t})$ are more unwieldy than for functions K_{ij} and the FORTRAN expression for H_{ij} can be obtained by E-mail from the author on request ¹.

We shall also calculate the dominant contribution in total and differential inclusive J/ψ photoproduction cross sections from $\gamma g \rightarrow J/\psi g$ partonic subprocess. Here we present main formula for this one without discussion (see, for example [7]).

First the partonic differential cross section is given by:

$$\frac{d\hat{\sigma}}{d\hat{t}}(\gamma g \rightarrow J/\psi g) = B_{\gamma g} M_J^4 F(\hat{s}, \hat{t}), \quad (20)$$

where

$$B_{\gamma g} = \frac{8\pi\alpha_s^2\Gamma_{ee}}{3\alpha M_J},$$

$$F(\hat{s}, \hat{t}) = \frac{1}{\hat{s}^2} \left[\frac{\hat{s}^2(\hat{s} - M_J^2)^2 + \hat{t}^2(\hat{t} - M_J^2)^2 + \hat{u}^2(\hat{u} - M_J^2)^2}{(\hat{s} - M_J^2)^2(\hat{t} - M_J^2)^2(\hat{u} - M_J^2)^2} \right].$$

Here: $\hat{s} + \hat{t} + \hat{u} = M_J^2$, $\hat{t}_{max} = 0$ $\hat{t}_{min} = -\hat{s} + M_J^2$.

The total partonic cross section reads:

$$\hat{\sigma}(\gamma g \rightarrow J/\psi g) = B_{\gamma g} M_J^4 \Phi(\hat{s}), \quad (21)$$

where

$$\Phi(\hat{s}) = \frac{2}{(\hat{s} + M_J^2)^2} \left[\frac{\hat{s} - M_J^2}{\hat{s} M_J^2} - \frac{2 \ln(\hat{s}/M_J^2)}{\hat{s} + M_J^2} \right] +$$

$$\frac{2(\hat{s} + M_J^2)}{\hat{s}^2 M_J^2 (\hat{s} - M_J^2)} - \frac{4 \ln(\hat{s}/M_J^2)}{\hat{s}(\hat{s} - M_J^2)^2}.$$

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3 Associated J/ψ plus charm photoproduction on proton

Let us consider the kinematic for process $\gamma p \rightarrow J/\psi + c + X$ in the rest frame of the proton (the lab. frame). Variables of partonic subprocess $\gamma c \rightarrow J/\psi c$ and variables describing measurable process are connected as follows:

$$\hat{s} = xs + m^2, \quad \hat{t} = 5m^2 - xzs, \quad \hat{u} = -xs(1 - z),$$

where (in lab. frame) $s = 2m_p E_\gamma$, $z = E_J/E_\gamma$, x is a momentum fraction of charm quark in the proton. In the general factorization approach of QCD the measurable cross section σ and partonic cross section $\hat{\sigma}$ are connected by the following expressions:

$$\sigma(\gamma p \rightarrow J/\psi c X) = \int_{x_{min}}^1 dx C_p(x, Q^2) \hat{\sigma}(\gamma c \rightarrow J/\psi c), \quad (22)$$

where $x_{min} = 8m^2/s$, $Q^2 = M_J^2$ and

$$\frac{d\sigma}{dz}(\gamma p \rightarrow J/\psi c X) = -s \int dx x C_p(x, Q^2) \frac{d\hat{\sigma}}{d\hat{t}}(\gamma c \rightarrow J/\psi c), \quad (23)$$

where the region of integration over x is defined by the condition: $\hat{t}_{min} < 5m^2 - xzs < \hat{t}_{max}$.

At present the direct experimental information about charm quark distribution function in a proton in wide region of x is practically absent. Existing parameterizations of $C_p(x, Q^2)$ are very different. For comparison we shall use in our calculation "hard" scaling parameterization [1]:

$$C_p(x, Q^2) = C_p(x) = 18x^2[(1-x)(1+10x+x^2)/3 + 2x(1+x)\ln x] \quad (24)$$

and "soft", based on perturbative QCD, parameterization [11] at the scale $Q^2 = M_J^2$:

$$xC_p(x, Q^2) = (s - s_c)^a (1 + Bx)(1 - x)^D \exp\left(-E + \sqrt{E's^b \ln(1/x)}\right), \quad (25)$$

where

$$\begin{aligned} a &= 1.01, \quad b = 0.37, \quad s_c = 0.888, \quad B = 4.24 - 0.804s, \quad D = 3.46 + 1.076s, \\ E &= 4.61 + 1.49s, \quad E' = 2.555 + 1.961s, \quad \mu^2 = 0.25 \text{ GeV}^2, \quad \Lambda = 0.232 \text{ GeV}, \end{aligned}$$

$$s = \ln \left(\frac{\ln(Q^2/\Lambda^2)}{\ln(\mu^2/\Lambda^2)} \right).$$

Note that mean value of the proton momentum, which is carried by charm quarks, is equal to 0.3% in the case of parameterization [1] and approximately 0.5% in the case of parameterization [11], which does not contradict data from EMC Collaboration on $F_2^c(x, Q^2)$ [12].

These parameterizations for $C_p(x, Q^2)$ have very different physical interpretation. The scaling parameterization [1], so-called "intrinsic", was obtained assuming existence of a small, but finite, non-perturbative charm component in proton wave function. It is necessary for description of open charm and J/ψ production total cross section and x_F spectra at $x_F \rightarrow 1$ in hadron-hadron and hadron-nucleus collisions. On the contrary, the parameterization [11], so-called "extrinsic", strongly depends on choice of scale Q^2 , because it was obtained in perturbative QCD approach assuming that at $Q^2 < Q_{min}^2$ charm quarks in the proton are absent and they are generated in QCD cascade only at large Q^2 .

In Fig.2 the x dependence of the charm distribution function is shown at $Q^2 = M_J^2$. As it will be discussed later different x -dependences of the charm distribution functions give us very different predictions for total J/ψ photoproduction cross section as a function of energy.

4 Results and discussion

Result of calculation of total cross section as function of photon energy E_γ for associated J/ψ plus open charm photoproduction in approach discussed above is shown in Fig.3. "Intrinsic" parameterization [1] predicts largest value of cross section at energies $E_\gamma \leq 60$ GeV, but this cross section rapidly decrease as energy growth at $E_\gamma \geq 100$ GeV. On the contrary, the cross section, which was calculated using "extrinsic" parameterization [11], monotonously increase from $5 \cdot 10^{-3}$ nbn at the energy $E_\gamma = 50$ GeV to 0.4 nbn at the energy $E_\gamma = 5$ TeV and at the energy range of ep -collider HERA ($\sqrt{s}_{\gamma p} = 200$ GeV) it is approximately equal to 0.8 nbn (Fig.4). Such a way we have sufficiently large measurable cross section of the J/ψ plus open charm production for direct experimental investigation of the x -dependence of charm quark distribution function in a proton.

The study of the J/ψ photoproduction in γp -interactions concentrated on inelastic J/ψ production as a tool to obtain information on the gluon distribution function in a proton [5]. That is why we have calculated the contribution of the $\gamma c \rightarrow J/\psi c$ partonic subprocess in the total inclusive J/ψ photoproduction cross section. Fig.4 shows result of calculation this contribution using "extrinsic" parameterization [11] as well as contribution

of the dominant photon-gluon fusion subprocess as functions of $\sqrt{s}_{\gamma p}$. It is known that $\gamma g \rightarrow J/\psi g$ partonic subprocess gives contribution in the total inclusive J/ψ photoproduction cross section approximately equal to 50% at the energy $\sqrt{s}_{\gamma p} = 200$ GeV [5]. Our calculation shows that total contribution of the subprocesses $\gamma c \rightarrow J/\psi c$ and $\gamma \bar{c} \rightarrow J/\psi \bar{c}$ at the energy $\sqrt{s}_{\gamma p} = 200$ GeV is equal to 4% of the photon-gluon fusion subprocess contribution or 2% of the total contribution of all mechanisms. The contribution of the charm quarks in J/ψ photoproduction cross section may be significant and approximately equal to contributions of elastic (5%) or diffractive (2%) mechanisms [5]. But at smaller energies $\sqrt{s}_{\gamma p} = 10 - 20$ GeV charm quark and antiquark contribution is 15% of photon-gluon fusion contribution in the case of parameterization [1] for charm quarks in the proton.

The contribution of the proton intrinsic charm in J/ψ photoproduction must be very large in the region of proton fragmentation that is at small $z = E_J/E_\gamma$ in the proton rest frame. Figs. 5 and 6 show results of calculation for contributions $\gamma c \rightarrow J/\psi c$ and $\gamma g \rightarrow J/\psi g$ partonic subprocesses in z -spectra of the J/ψ photoproduction at energies $\sqrt{s}_{\gamma p} = 14.7$ GeV and $\sqrt{s}_{\gamma p} = 200$ GeV, correspondingly. The charm quark contribution is larger than photon-gluon fusion subprocess contribution at $z < 0.2$ for both energies. At the relatively small energy ($\sqrt{s}_{\gamma p} = 14.7$ GeV) the parameterization [1] gives more large contribution. At the energy $\sqrt{s}_{\gamma p} = 200$ GeV the contribution of parameterization [1] is largest only for very small $z < 10^{-3}$, in the region $10^{-3} < z < 0.2$ the contribution of parameterization [11] is dominant.

In conclusion we note that the comparison of our results with data didn't made because data usually have been obtained in fixed kinematical region of variables z and p_T ². In contrary in our approach total kinematical region (It is bounded by conservation laws) of these variables have been took into account. But all calculations were made in the same kinematical approximation and we can to compare relative contributions of the different mechanisms with data. The calculations for total cross section, z and p_T spectra of the J/ψ photoproduction via partonic subprocess $\gamma c \rightarrow J/\psi c$ in fixed kinematical region (HERA collider, for example) will be present in future publications.

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²The introduction of the normalization K-factor is needed too

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Figure captions

1. Diagrams used to describe the partonic subprocess $\gamma c \rightarrow J/\psi c$.
2. The charm distribution function in a proton versus x at $Q^2 = M_J^2$. The curver 1 corresponds to parameterization [1], the curve 2 - [11].
3. The cross section of the process $\gamma p \rightarrow J/\psi X$ as a function of photon energy E_γ . Curves as the same Fig.2.

4. The cross section of the process $\gamma p \rightarrow J/\psi X$ as a function of $\sqrt{s}_{\gamma p}$. The curver 1 corresponds to subprocess $\gamma c \rightarrow J/\psi c$ (parameterization for $C_p(x, Q^2)$ is taken from [11]), the curver 2 - $\gamma g \rightarrow J/\psi g$ (parameterization for $G_p(x, Q^2)$ is taken from [11] too).
5. The z - spectrum of J/ψ in γp - interaction at $\sqrt{s}_{\gamma p} = 14.7$. Curvers 1 and 2 - contributions of $\gamma c \rightarrow J/\psi c$ subprocess used parameterizations [1] and [11], correspondingly. The curver 3 - contribution of photon-gluon fusion mechanism.
6. As the same Fig. 5 at $\sqrt{s}_{\gamma p} = 200$ GeV.

Abstract

Based on a perturbative theory of quantum chromodynamics and non-relativistic quark model, associated J/ψ plus open charm photoproduction on charm quarks in a proton via partonic subprocess $\gamma c \rightarrow J/\psi c$ is discussed. It is shown that the value and energy dependence of the cross section for such process remarkably depends on the choice of charm distribution function in a proton. In the region of small $z = E_J/E_\gamma < 0.2$ the contribution of the $\gamma c \rightarrow J/\psi c$ subprocess in the inelastic J/ψ photoproduction spectra is larger than the contribution of the photon-gluon fusion subprocess. At the energy range of HERA collider charm quarks contribution in the total inclusive J/ψ photoproduction cross section may be equal to 4% of the dominant contribution of photon-gluon fusion mechanism.

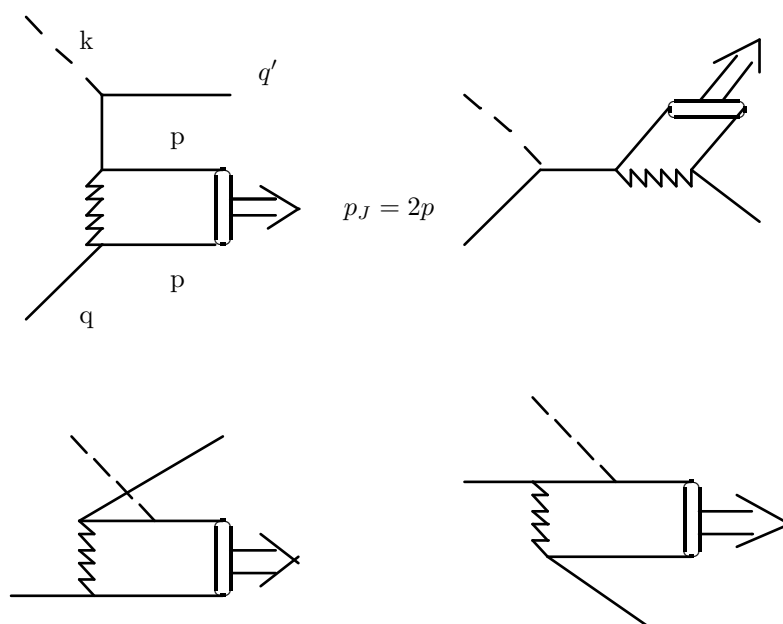


Fig. 1

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